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Full Length Article

Combining preformed particle gel and low salinity waterflooding to improve conformance control in fractured reservoirs

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A R T I C L E I N F O

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A B S T R A C T

The recovery from fractured reservoirs is usually low. The areal heterogeneity is one result of the fractured reservoir. Low salinity waterflooding (LSWF) and preformed particle gel (PPG) have recently drawn great interest from the oil industry. LSWF can only increase displacement efficiency, and it has little or no effect on sweep efficiency whereas PPG can plug fractures and improve sweep efficiency, but they have little effect on displacement efficiency. The coupled method bypasses the limitations of each method when used individually and improves both displacement and sweep efficiency.

The main objective of this study was to determine whether the combining technologies can improve conformance control in fractured sandstone reservoirs. Before the study was conducted, the effects of low salinity waterflooding, number of fractures, and PPG strength were studied. The PPG was injected into the fracture at a flow rate 2.0 ml/min. Brine was injected at a different flow rate after PPG placement to test the effect of flow rate on the PPG's plugging efficiency. Laboratory experiments showed that the oil recovery factor and the Frrw increased when the concentration of injected brine changed from conventional salinity to low salinity and the areal sweep efficiency was improved. However, the PPG extruded pressure decreased when the PPG swelled in a low-brine concentration. At a high-flow rate, there was no significant effect on the Frrw. Combining two different EOR technologies can improve displacement and sweep efficiency and, in turn, enhance conformance control.

1. Introduction

The oil industry continuously seeks methods to recover the approximately two-thirds of oil in place that cannot be recovered by conventional techniques. Many mature wells are abandoned when faced with low oil production rates and excess water production. Preformed particle gel (PPG) control conformance and low salinity waterflooding (LSWF) were two EOR technologies were successfully applied to recover this oil.

Waterflooding sweep efficiency in fractured reservoir is improving by using PPG. Some problems of in situ gelation systems, such as a lack of gelation time control, gelling uncertainty due to shear degradation, chromatographic fractionation, or dilution by formation water can be resolved by PPGs [1–3]. PPGs usually have only one component during injection and they are sensitive to the physicochemical conditions of a reservoir, including pH, multivalent ions, hydrogen sulfide, salinity, and temperature [2,3] Commercial particle gels come in a number of sizes: micro- to millimeter-sized PPGs [5,2–4], microgels [6], pH-sensitive crosslinked polymers [7,8], and swelling submicron-sized polymers [9,10]. The literature review shows that PPGs, microgels, and submicron-sized polymers are cost-effective means to decrease water production and improve the oil recovery of mature oil fields. Submicron-sized particles were successfully used to treat more than 60 wells [11]. Microgels were applied to about 10 gas storage wells reduced water production [6]. Millimeter-sized PPGs can penetrate into fractures or fracture-feature channels and also lessen gel penetration into unswept zones/matrices. About 10,000 wells were treated by PPGs applied to reduce the permeability of fractures or of super-high permeability channels [12].

To decrease the residual oil saturation in swept areas, the use of LSWF or low salinity waterflooding has been studied at length. The first research on the effect of low-salinity water on oil recovery was introduced by Martin (1959) [13]. He used sandstone core samples, comparing an injection of seawater to that of freshwater. Martin found that freshwater increased oil recovery more than seawater. Despite Martin's (1959) groundbreaking work, it was not until Morrow et al. presented research in the 1990s showing the potential of LSWF [14–18]. Since that time, additional studies have been done by

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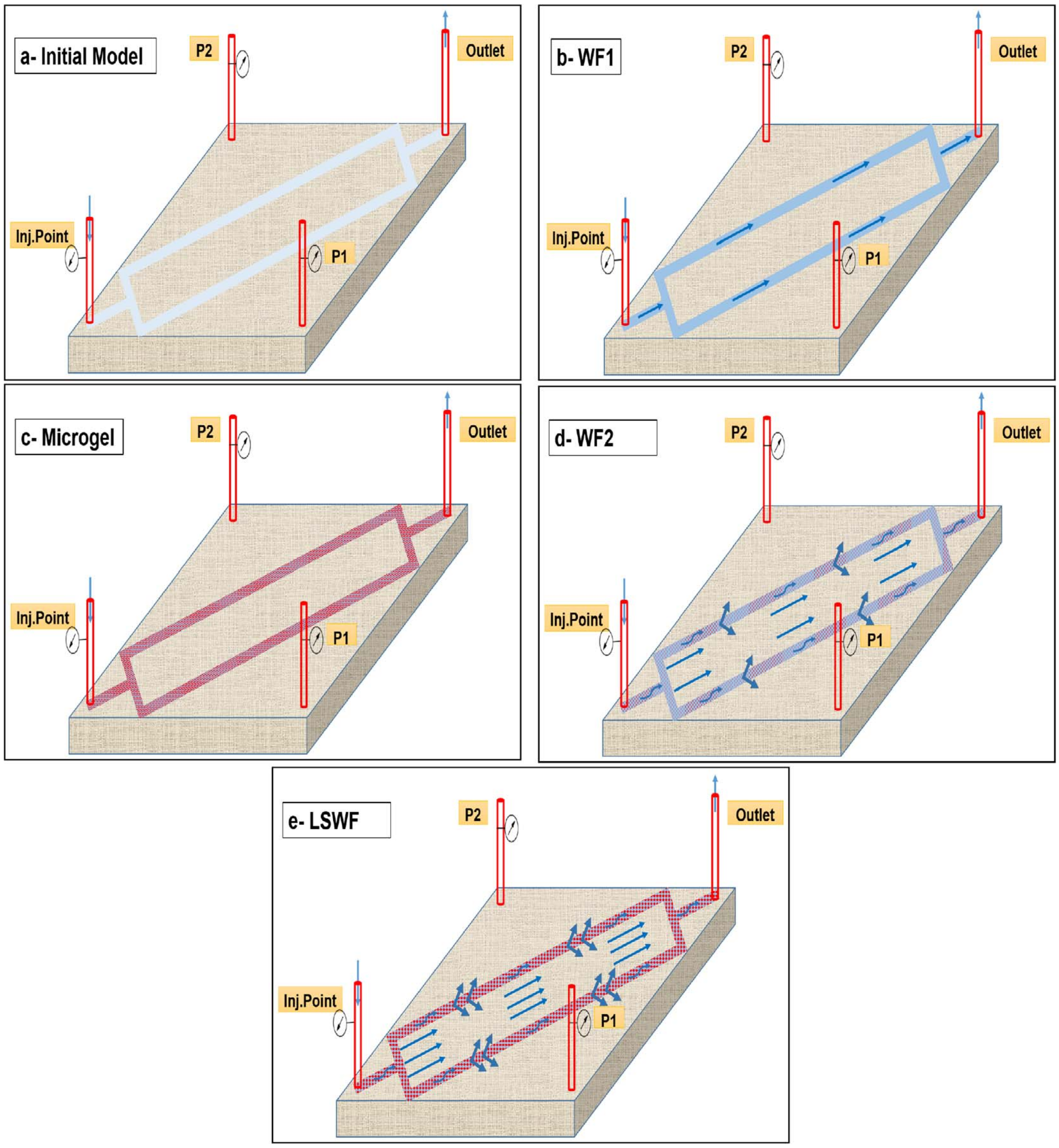

Fig. 1. Schematic showing the PPGs mechanism's in closed fracture (a) initial model, (b) first waterflooding, (c) microgel injection, (d) second waterflooding, and (e) low salinity waterflooding.

corporations, research groups, and individuals to learn more about the relationship between water salinity and oil recovery, especially in sandstone and carbonate rocks (limestone). Laboratory studies have corroborated that LSWF can enhance oil recovery in sandstone and carbonate reservoirs [19]. Zhang et al. (2007) [20] showed that injecting low-salinity water into chalk formations produced oil recovery of up to 40 percent of a reservoir's original oil in lace (OOIP). Studies by McGuire and Chatham (2005) [21] and Lager et al. (2008) [22] found that with LSWF, oil recovery increased up to 40 percent of the OOIP. Compared to normal waterflooding in sandstone formations, LSWF is much more effective in reducing residual oil saturation [21,23–25]. However, the amount of improvement in oil recovery improvement depends upon multiple factors, such as multicomponent ion exchange, clay content, formation water composition, oil composition, and initial water saturation. Much research has been conducted to explain the benefits of LSWF, which includes positive results related to the following: the migration of fines [18], interfacial tension reduction [21], multicomponent ionic exchange [22], pH-driven wettability change [21,22], double-layer expansion [24], desorption of organic material from clay surfaces [26], wettability alternation [25], mineral dissolution [27], and microscopically diverted flow [28,29]. One commonality of the aforementioned factors is that they modify rock wettability from oil-wet or intermediate/water-wet, resulting in reduced saturation and improved total oil recovery. Therefore, LSWF contributes to EOR by improving the microscopic displacement efficiency. Even though Yousef et al. (2011) have used 10,000 ppm as their base brine, Morrow and Buckley (2011) reported that low salinity effect has been reported for brine compositions of up to 5000 ppm. For LSW at Sor, injection waters with compositions in the range of 2000–3000 ppm have been used in field tests. Also, Kasmaei et al. (2014) used 10,780 ppm (1.078%) as base salinity. They used dolomite reservoir cores from Kocurek Industries to represent carbonate reservoir rock. Webb et al. (2005a) concluded that to get a low-salinity benefit the salinity should be as low as 4000 ppm. Also, Emad W. Al-Shalabi and Kamy Sepehrnoori (2016) reported that Bernard (1967) concluded that no effect of saline water 15% to 1% NaCl on oil recover; however; both oil recovery increased when the NaCl concentration was decreased from 1% to 0.1%.

Oil recovery is enhanced when both the displacement efficiency (ED) and the sweep efficiency (ES) improve. Low salinity waterflooding increases the displacement efficiency; however, the sweep efficiency is only affected slightly, if at all. In contrast, PPGs have little effect on the